DEVELOPMENT OF THE HARDWARE-SOFTWARE COMPLEX PIRS-5 FOR FIELD MEASUREMENTS IN ACCELERATING STRUCTURES

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Abstract

Hardware-software complex «PIRS-5» was developed to make measurements in warm accelerating structures. The idea was to create full-automatic measuring system, which can measure electrical field at the bead position with non-resonant and resonant pull techniques. PIRS-5 has postprocessor, which calculate electrical component from the frequency, reflection or transmission coefficient, shunt and effective shunt impedance. This work describes the construction of this complex, its mathematical part and possible future modifications.

PIRS-5 LAYOUT AND SCHEMATICS

Measurement setup PIRS-5 is software and hardware complex developed for electrodynamical characteristics measurements of accelerating structures. "PIRS" is acronym for Russian "facility for resonator parameters measurements" initially developed at MEPhI by Prof. A.Ponomarenko and his research team. After series of renovations and upgrades it became powerful tool for accelerating structures research nad development led by RF lab tem at MEPhI. Vector network analyzer being the key element of this setup is able to measure resonant frequencies and quality factors without any additional hardware or software involved. But field distribution inside accelerating structure and corresponding parameters like shunt impedance are not so easily acquired. In this paper new upgraded version is described. Algorithms and software part were substantionally altered and redesigned. Both resonant and non-resonant measurements of electromagnetic fields became possible using this implementation. New software allows computation of shunt impedance and effective shunt impedance computation based on electric field measured.

Measurement setup schematics is illustrated on Fig. 1. It is quite ordinary hardware for this kind of measurements based on small perturbation technique. It includes Vector network analyzer Agilent 8753ET (1), control PC (2), accelerating structure under test (3), coupling antenna (4), small dielectric or metal bead (5), bead moving and positioning system (6) actuated by step motor (7). Latter is powered and PC controlled via step motor controller (8).

It was already mentioned, that Agilent VNA is the main RF measuring device able to acquire accelerating structure parameters operated up to 6 GHz. Bidirectional GPIB interface connects it to PC and provides VNA control and data transfer. Accelerating structure under test is connected to VNA port by one or two coupling pickups chosen accordingly to particular measurement task. Small dielectric or metal perturbing bead attached to nylon string is travelling along cavity axis. Mechanical system allows precise

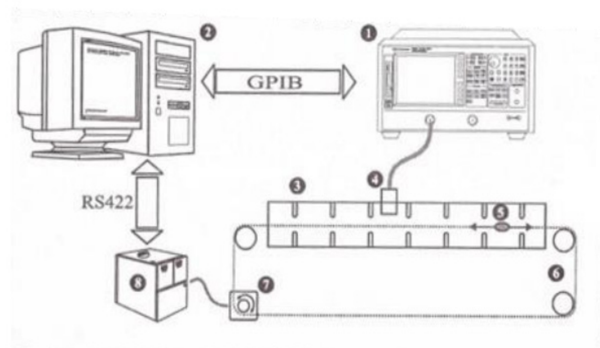

Figure 1: PIRS-5 layout.

string alignment and bead position determination. Computer controls all the hardware, provides data storage and user interface.

PIRS-5 SOFTWARE

Control software developed for PIRS-5 consists of two main algorithms (see Fig.2).

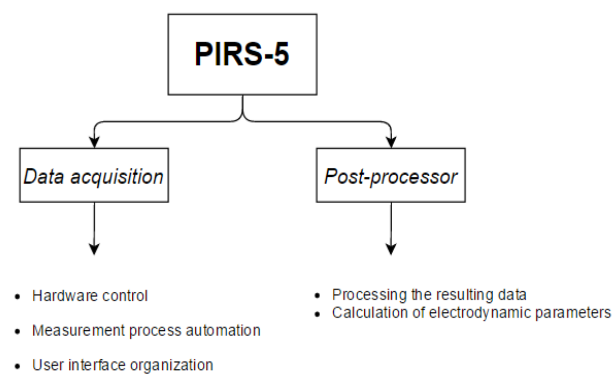

Figure 2: PIRS-5 software.

They are algorithm of data acquisition and post-processor. Let us consider algorithm features paying brief attention to the user interface implementation details. After user enters cavity length, measured quality factor and bead form-factor program starts measurement. This algorithm is illustrated on Fig. 3.

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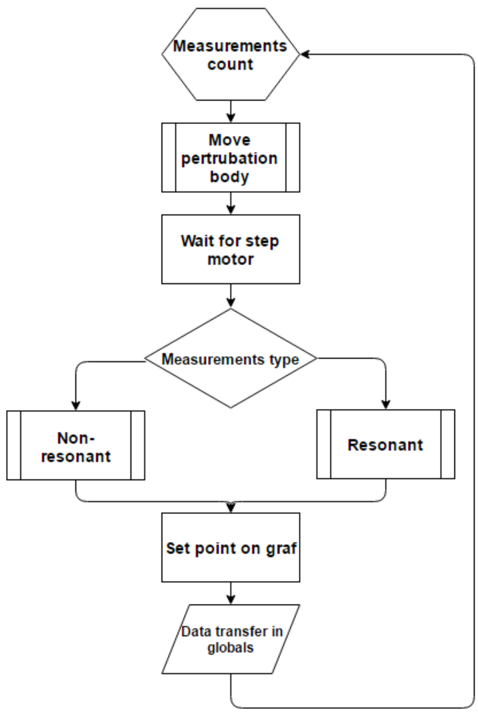

Figure 3: Field measurement algorithm.

Dedicated subroutine for data acquisition and step motor control algorithm is shown on Fig.4. There are several operations repeated in loop in this algorithm. At first step VNA is addressed to make measurement and transfer data to PC. Then it is analyzed converted from raw string to real type.

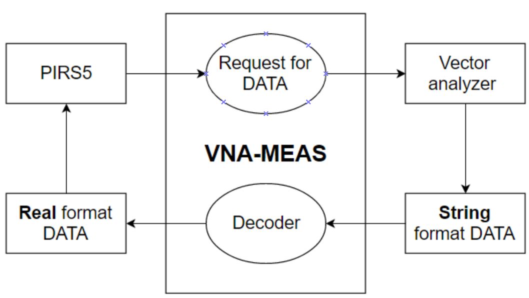

Figure 4: Subroutine for data acquisition algorithm.

FIELD DISTRIBUTION BASED ON FREQUENCY MEASUREMENTS

As it was mentioned earlier measurement setup allows to perform measurements of electric field longitudinal component E_z. Resonant frequency variation under perturbing bead influence was initially used as basic method of E_z computation. Well-known Slater formula [2] was used for field computation

$$\frac{\Delta f}{f_0} = \frac{f_p - f_0}{f_0} = -k_{\Delta f}^E |E|^2 / U \,. \quad (1)$$

rewritten as

$$\xi_z = \sqrt{\frac{\Delta f}{2\pi k_{\Delta f}^E f_0^2}} \frac{\Omega^{1/2}}{m} \,. \quad (2)$$

where f_0 (f_p) – unperturbed / perturbed cavity frequency, |E| - field strength in bead location, U – electromagnetic field stored energy, ξ_z – field strength factor equal to $E/\sqrt{PQ}$, $k_{\Delta f}$ – bead form-factor.

Later additional algorithms were added allowing one to measure E_z via real and imaginary parts of reflection coefficient.

FIELD DISTRIBUTION BASED ON REFLECTION FACTOR MEASUREMENS

Field amplitude and phase in n-th cell could be directly calculated using recurrent formulas [3]:

$$E_{n+1} = E_n \sqrt{\left| \frac{\Delta \dot{S}_{11}^{(n+1)}}{\Delta \dot{S}_{11}^{(n)}} \right|}, E_1 = 1; . \quad (3)$$

$$2(\varphi_{n+1} - \varphi_n) = \arg\left(\frac{\Delta \dot{S}_{11}^{(n+1)}}{\Delta \dot{S}_{11}^{(n)}} \right), \varphi_0 = 0. . \quad (4)$$

It is supposed that at the first cell field amplitude is 1 and phase to zero. This generic normalization becomes a problem while shunt impedance computation. Therefore we chose another approach for absolute field strength values computation based on raw acquired data processing.

In [1] the bead form-factor difference for TW and SW modes is discussed. It was shown that these two values necessary for E_z calculation are defined as

$$k_{\Delta f} = \frac{|\Delta f|}{f_0 \dfrac{|E|^2}{U}} \; ; \; k_{\Delta S11} = \frac{|\Delta \dot{S}_{11}|}{\left(1 - \left|\dot{S}_{11}^0\right|^2\right) Q_0 \dfrac{|E|^2}{U}} \quad (5)$$

and their relationship could be derived:

$$k_{\Delta S11} = \frac{|\Delta \dot{S}_{11}| f_0}{\left(1 - \left|\dot{S}_{11}^0\right|^2\right) Q_0 |\Delta f|} k_{\Delta f} \,. \quad (6)$$

Using latter equation substituted in (2) we obtain

$$\xi_z = \sqrt{\frac{|\Delta \dot{S}_{11}|}{2\pi f_0 k_{\Delta S11} \left(1 - \left|\dot{S}_{11}^0\right|^2\right) Q_0}} \frac{O M^{1/2}}{M} \,. \quad (7)$$

where $|\Delta S_{11}|$ reflection absolute value alteration caused by perturbing bead, f_0 and $|(S_{11}^0)^\cdot|$– resonant frequency and reflection without perturbation, Q_0 – cavity quality factor.

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FIELD DISTRIBUTION BASED ON PHASE MEASUREMENTS

This algorithm used as n option is based on known approach used for example by Jefferson Lab. We adopted it for our case and finally equations

$$\Delta f \big/ f_0 = \frac{\tan\left(\Delta \arg\left(S_{21}\right)\right)}{2Q} \quad . \tag{8}$$

and

$$\xi_z = \sqrt{\frac{\tan\left(\Delta \arg\left(S_{21}\right)\right)}{4\pi k_{\Delta f}^{E} f_0 Q}}\, \frac{OM^{1/2}}{M} \quad . \tag{9}$$

were used in algorithm.

Executable code consisting of user interface and service subroutines with all algorithms discussed above was developed using LabView environment.

PIRS5 TESTING

Wideroe based cavity with modified drift tubes stems which is under development at lab was used for testing of measurement setup. This cavity and field distribution along cavity axis obtained earlier using numeric simulation are presented on Fig. 5.

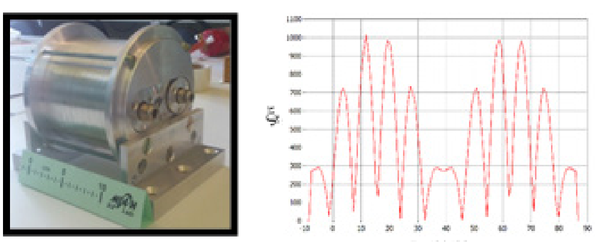

Figure 5: Cavity used for measurement setup tests and simulated Ez(z) field distribution.

Results of field measurements using the same hardware (including bead) but with different methods discussed above are presented on Fig. 6.

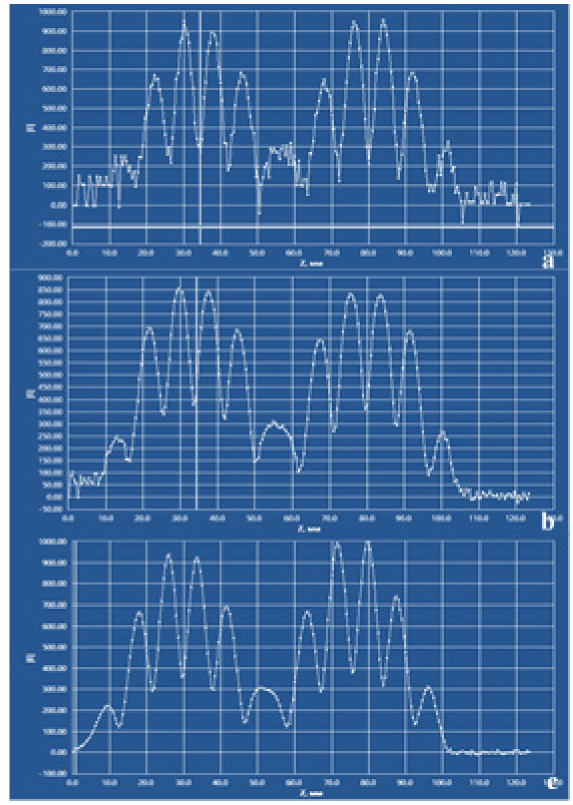

Figure 6: Cavity Ez(z)distributions acquired using easurements of: frequency variation (a), reflection (b) and phase (c).

CONCLUSIONS.

PIRS5 measurement setup used at MEPhI RF laboratory for accelerating cavities low power measurements was considerably upgraded. New algorithms of field strength computation based on different electrodynamical characteristics measured were implemented. After tests it is used as multipurpose tool for low power measurements of accelerating structures under development.

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